TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

LIBRARY

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VOLUME I—No. 2
FEBRUARY 1936

32 VICTORIA STREET
LONDON SW1

NOTES ON RECENT MEETINGS AND EVENTS

Meetings in London.

A meeting of the Society was held in the Lecture Theatre of the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1, on Tuesday, January 14, 1936. The chair was taken by the President (Mr. A. W. Beuttell) at 7 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

The President then called upon Mr. F. E. Lamplough to deliver his introductory paper entitled "Applications of Ultra-Violet Light and Some Aspects of Fluorescence and Phosphorescence." The paper contained an account of some of the chief characteristics of fluorescence, the materials exhibiting this effect and the apparatus available for its excitation. The application of fluorescent effects as a means of analysis was illustrated by examples. In conclusion, a brief account of phosphorescence was given.

The discussion was opened by Dr. Leonard Levy, who gave an account of recent progress in the production of fluorescent materials for X-ray screens, television, etc., and exhibited a series of pictures illustrating the application of fluorescence for purposes of display. Others who took part in the discussion or arranged demonstrations were Mr. F. P. Bentham, Mr. C. H. Wright, Dr. H. J. Plenderleith (British Museum), Mr. W. J. Scott, Mr. J. T. Randall, Mr. H. G. Jenkins. In the absence of Mr. F. H. Vallency, the president of the London Stamp Club, who was unable to attend owing to indisposition, Mr. J. S. Dow illustrated the use of fluorescence in testing rare postage stamps.

A feature of the meeting was the number and variety of demonstrations illustrating the application of fluorescent effects in practice. The President, in winding up the proceedings, proposed a cordial vote of thanks to Mr. F. E. Lamplough for his paper and to those who had contributed so much to the interest of the evening by arranging exhibits.

Events Postponed.

Owing to the passing away of His Majesty King George V. it was considered expedient to postpone several items on the programme. The opening meeting of the Photometric Section, which was to have taken place on January 28, was postponed until February 4. The meeting of the North-Western Local Centre, originally arranged for January 21, was also postponed, but it is hoped to announce very shortly another date for the reading of the paper by Mr. A. G. Brown and Mr. A. L. Whittenham on "The World's Most Modern Fish Dock."

After careful consideration, it was also decided to postpone the annual dinner. The revised date for this (March 24) has already been announced.

The Library Fund.

Although an encouraging response to the circular issued in regard to the proposed formation of a library has been received, the Hon. Secretary would still welcome (a) donations to the fund, (b) offers or suggestions in regard to books, and (c) offers of assistance in preparing lists.

The next step should be the preparation of fairly complete lists of available or desirable books, after which the more difficult problems of devising a practicable method of storing volumes and making them accessible to members will receive consideration.

Applicants for Membership.

Elections Pending:—

The following names were presented at the general meeting of the Society on Tuesday, January 14, 1936:—

SUSTAINING MEMBERS:—

Robinson King and British Challenge Glazing Co., Ltd....Marshgate Lane, Stratford LONDON, E.15.

(*Representative*:—Mr. G. Lovell.)

Troughton and Young, Ltd.....143, Knightsbridge, LONDON, S.W.1.

(*Representative*:—Mr. John Hall.)

CORPORATE MEMBERS:—

Ives, W. A.....Harcourts, Ltd., 21a, Newman Street, LONDON, W.1.

Lewzey, L. H.....32, Battledean Road, Highbury, LONDON, N.

Lucas, G. S. C.....64, Fisher Avenue, RUGBY.

New, J.....Dibbles, West Clandon, Guildford, SURREY.

COUNTRY MEMBERS:—

Andrew, J.....13, Pulcroft Road, Hessie, E. YORKS.

Robertson, R. D.....Public Lighting Department, 1, Irvine Square, DUNDEE.

Elections Completed:—

At this meeting the names of those announced on November 12, which were published in the last issue of the "Transactions" (Vol. 1, No. 1, p. 2, Jan., 1936), were read again, and these applicants were formally declared members of the Society.

THE PHOTOGRAPHIC REPRESENTATION OF STREET LIGHTING INSTALLATIONS

By R. G. HOPKINSON, B.Sc. (Eng.)

(Communication from the Staff of the Research Laboratories of The General Electric Company, Limited, Wembley, England).

(Paper read at the Joint Meeting with the Royal Photographic Society of Great Britain, on Tuesday, December 17th, 1935.)

SUMMARY.

The paper discusses the problem of street lighting photography in detail. A system of representation, derived from first principles, is given, enabling the photographer to produce a qualitative record of engineering value. Full theoretical treatment is given and concise instructions for the practical application of the system are incorporated in the paper.

Introduction.

The increasing reliance placed on visibility as the true criterion of the merits of street lighting installations has given a new significance to street lighting photographs. Photographs, to be of engineering value, must be capable of being critically examined, so that the road surface can be carefully inspected, the shape, size, and brightness of the bright patches noted, and the probable visibility in the dangerous dark patches accurately estimated. Such extremely critical judgment is rarely brought to bear on any other type of photograph. It is to be regretted that under this critical judgment, the type of photograph at present being produced is often valueless.

It has been a cause of general comment, voiced by the authors of recent papers on street lighting, that street lighting photographs are quite unreliable as a means of studying the characteristics of an installation. In the absence of any system of representation the photographer has produced in his final print the impression he received of the street during his brief acquaintance with it, or instead has concentrated on the pictorial effect.

There does not appear to be any major technical difficulty which prevents a logical system being formulated. The usual problems of subjective reproduction do not occur. Colour plays little part in the distinguishing of objects at the comparatively low brightnesses encountered in street lighting work, so that little is lost by a monochromatic rendering of an installation.

The object of this work has been to develop a logical system of representation derived from first principles, so that photographs, i.e. prints, prepared in accordance with the system will give a qualitative record of the installations they represent, as well as being comparable amongst themselves. Such photographs may not always make the most attractive pictures. A fact which emerged in the course of the investigation was that if a number of prints with different characteristics was made, the print first chosen by memory as most nearly representing the installation was generally brighter and more plucky than the print chosen afterwards under proper viewing conditions in the street. This is because the memory at first tends to flatter the installation. It is only after considerable experience in the judgment of street lighting photographs that an observer realises that the more pleasant result is not necessarily the more accurate from an engineering point of view. It is necessary to bear this in mind when judging photographs, for it is required to record the installation as seen, and not the installation as recalled

Photographic Reproduction.

For an understanding of the technique to be described, it is desirable that the reasons why a photograph can be a faithful reproduction of a scene should be appreciated. It is well known that photographic representations can be made of a brilliantly lighted snow scene, of a dark interior of a house, or of a dimly lighted street at night, and that each will convey an accurate impression of the original. This range of subjects, with brightnesses varying 100,000 to 1 from the bright snow to the dark street corner, can all be reproduced successfully on the same photographic paper with its limited range of less than 100 to 1. Further, any of the prints can be viewed under a wide range of illuminations varying from low power interior lighting to summer sunlight, with little change in the impression given by the print, although its brightness may be changed a thousand times. Apparently, therefore, the impression conveyed is independent of brightness, whilst at the same time a print which is printed a little too light or too dark is immediately criticised.

There are very good reasons for this apparently contradictory state of affairs, which is due to the properties of the eye. Although the eye can operate satisfactorily from sunlight to moonlight the range of brightness that it can perceive at any one moment is limited. For example, if one is outside a house with an open door, it is usually impossible to distinguish much detail inside the door, because the eye is adapted to the average brightness of the objects outside the house. Those inside are so dark as to be beyond the limiting lower brightness that the eye can detect with that adaptation, although the actual interior may appear to be well lighted to a person inside. Similarly, an attempt to resolve detail in the sun meets with complete failure because the brightness of the sun is beyond the upper limiting brightness. Consequently, it is not necessary for printing papers to be able to reproduce quantitatively the whole range of brightnesses encountered, but only that they should reproduce in the correct ratio

the range of brightnesses that the eye can perceive at a given time. Photographic materials have always fallen short of this ideal, but modern materials carefully handled can portray a range sufficiently great to enable accurate representations to be made, so that not much detail that could be seen by the eye is lost in the print. But as the range portrayed by the paper is not so great as the visual range, some detail must be lost in the shadows and in the high-lights. If the same amount is lost in each, a balance is obtained that gives the truest representation possible. But if a slight mistake in printing renders too much detail to be lost in the shadows, relatively to that lost in the high-lights, or vice versa, the balance is upset and the photograph is judged too dark or too light. This explains the second part of the apparent paradox of photographic reproduction.

STREET LIGHTING PHOTOGRAPHY.

When street lighting photographs are required as a technical record, no artistic licence is permissible in producing them. For example, Figs. 1, 2, and 3 are reproductions of three straightforward prints of a lighted street, produced without retouching or "controlled" printing.† Evidently the originals of these figures could not all give the best representation of the subject. There is a difference in contrast between Figs. 1 and 2, and a difference in general density between Figs. 1 and 3. Contrast and density are under control in the production of a photograph.

Prior to the present investigation, it was found possible to produce very fair representations by trial and error methods. The best of these efforts were examined to find if there were any fixed criteria on which they could be judged for the accuracy of their representation. The examination resulted in some definite conclusions on the mechanism by which a photograph is judged. Most certainly it can be judged, and most observers agree in their judgment. It was concluded that for an accurate record the following requirements must be fulfilled:—

Firstly, the photograph must be viewed from such a distance that subject is seen in correct perspective.

Secondly, the brightness gradation on the print must be the same as in the subject.

Thirdly, the detail visible in the highlights, and also in the shadows, should be strictly comparable with that visible in the subject.

These three requirements form the basis of the method to be described. While they may not exhaust the problem of true photographic reproduction, if fulfilled, they ensure the production of a photograph satisfactory in every way.

Principles of the Method.

1. *Correct Perspective.*—The first requirement, correct perspective, is simply that the angle subtended at the eye by an image on the photograph shall be the same as the angle subtended by the original subject. A photograph must therefore be viewed from a distance equal to the focal length of the equivalent lens system[1] by which the photograph was made. At first this point may seem to be trivial. It is, in fact, of great importance. An erroneous impression of a street can easily be gained by viewing, from the normal viewing distance of thirteen inches, a photograph taken with a 4-inch lens. The correctness of the reproduction suffers, the most evident effect being that any dark patches in the corners of the picture will appear large, out of all proportion to their true significance in the field of view. For general purposes, photographs should be printed so that the focus of the equivalent lens system is about normal reading distance, i.e. about thirteen inches, unless they are required for some special purpose; and also, when taking the photograph, the camera should be set at eye-level, i.e. five feet approximately.

There is a small refinement which, although not altering the faithful angular dimensions of the print, can be used to give it a more lifelike character. When a print is viewed at thirteen inches the eye is focused at that distance. When a street is viewed the eye is focused at, or near, infinity. This infinity eye focus can be obtained by looking through a lens, held close to the eye, whose focal length is the same as the viewing distance of the print. When this is done, no magnification is produced, but the eye operates as it normally would in a street, and conveys an impression of life and solidity to the print not otherwise present.

2. *Correct Contrast.*—It is a more formidable problem to reproduce subject brightnesses faithfully, and in the correct ratio. Before treating the subject in detail, the principles of the system which has been evolved can be outlined. In the normal photographic process there are three main controllable factors, exposure of the plate or film in the camera, development of the plate or film, and exposure of the print. It is taken for granted that a fully developed print is always required. The perfect photograph can only be produced by the control of all three factors, with the nature of the final result always in view. In practice it is convenient to standardise two factors and to control the third. For reasons to be explained later development cannot be the variable factor. If printing exposure is to be standardised, plate exposure must be varied. But if any error occurs, a fresh excursion to the installation must be made. If plate exposure be standardised, exposure in printing must be varied. Fortunately errors in printing are more conveniently remedied. Street lighting photographs can never be taken under conditions which approach comfort, so it is very necessary to make all work done in the installation as simple as possible.

As the first step in the production of a standardised negative, the exposure to be given to the plate must first be correlated to the range of subject brightness. *Exposure given must always be such that where*

† The half-tone illustrations in this paper are subject to the limitations described on page 30, and do not faithfully reproduce the original prints.

[1] The term equivalent lens system implies the focal length of the camera lens for a contact print, and the focal length of the camera lens times the degree of linear enlargement for an enlarged print.

possible the whole brightness range of the street surface is reproduced on the negative, and that the proportional representation of brightness is maintained throughout the range.

Development, which is the second step, controls the contrast of the negative. *Development given must always be such that the subject brightnesses are reproduced on the negative in the correct ratio.*

A negative produced in this way will be a true reversed monochromatic image of the subject. Effectively we have diminished and reversed the street and brought it into the darkroom. We are now at liberty to adjust the printing to produce the true impression conveyed by the street.

The third factor, the printing, must be adjusted so that in combination with the negative, the subject brightnesses[2] can be reproduced in their original ratios. This can be effected within close limits by suitable choice of printing material and control of developing technique.

3. *Correct Density.*—The reflection density of the print must now be controlled so that the third condition (page 20) is fulfilled. If the subject brightnesses are reproduced in the correct ratio, the whole photograph can be printed to the correct density, if it is possible to calculate the correct density to which one given datum brightness must be printed. The datum density can be determined from a consideration of the physiological characteristics of the eye The lower limit of brightness, below which, in a given scene, no detail can be perceived, is fixed relatively to the adaptation of the eye at any time. If the adaptation brightness of the eye (or the brightness of some part of the subject which bears some relationship to the adaptation brightness) be measured, the lower brightness limit corresponding to the subject can be found. This limiting brightness must then, by the present theory, be represented on the print by a density such that, when viewed under normal conditions, no detail can be seen in it, i.e., its brightness will be at the lower limit corresponding to the adaptation of the eye when viewing the print. Having settled the density to which this brightness should be printed, the scale for other brightnesses follows by direct proportion. Strictly speaking, the correct printing density varies with the illumination on the print, for this controls the adaptation brightness, and therefore the density for the lower brightness limit. But fortunately the characteristics of the eye are such that, as will be seen later, if the illumination on the print is over about five foot-candles the correct printing density varies very little. Below this illumination prints appear to be too dark, as they always do when seen by the darkroom light when developing them. If the correct density be found for about fifteen foot-candles, a print of this density will give a good representation in all illuminations from five foot-candles to 500 foot-candles

[2]The unit of brightness used throughout the paper is the equivalent foot-candle, which is defined as the brightness of a perfectly matt white surface of 100 per cent. reflection factor, illuminated to one foot-candle.

The Technique.

EXPOSURE AND DEVELOPMENT.

The detailed requirements in exposure and development can best be followed from a consideration of the characteristic curve of the photographic plate or film emulsion.

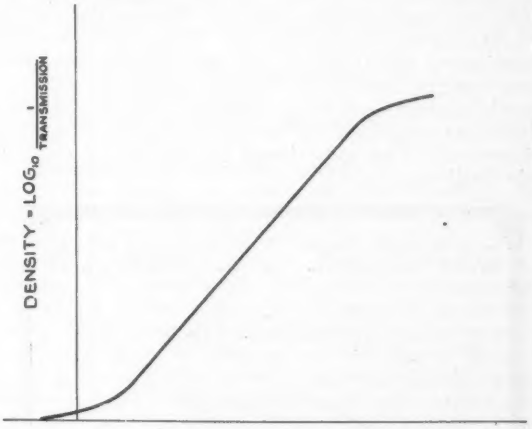


Fig. 4. Typical Plate Characteristic.

Figure 4 shows a typical curve which connects the density of the developed emulsion with the exposure to light. The scale of abscissae represents the logarithm of the product of illumination and time of exposure and the scale of ordinates, the image density or the logarithm of $\frac{1}{\text{transmission.}}$ Such a curve is usually straight throughout the greater part of its length. This means that between the abscissae of the points at either end of the straight line portion, the image density is a constant proportion of the logarithm of the product of illumination and time of exposure. If a given difference in incident light produces a proportional difference in the transmission of the plate, the slope of the line will be unity. Hence a negative of unity slope is a true reversed image of the subject. This type of negative is desirable for our purpose, and the factors that determine the slope must be carefully investigated.

EXPOSURE.

This characteristic curve of a photographic emulsion can also be applied to connect image density and subject brightness. If the plate or film be exposed in the camera to a subject, the illumination at any point on the plate is directly proportional to the brightness of the subject at the corresponding point, and depends on the light transmission of the lens system and aperture. Since there is a direct relationship between subject brightness and the illumination on the plate, the characteristic curve will give the connection between image density and subject brightness. The characteristic is more conveniently used in this form. It shows the range of subject brightness that can be included on the straight line portion of the characteristic for a given time of ex-

posure at a given stop. Conversely, if the brightness range of the subject be measured, a suitable time of exposure can be calculated for a given stop, to include this range on the straight portion of the characteristic curve, provided it is true to say that the same value of the product of illumination (and therefore brightness) and time of exposure always produces the same image density irrespective of the separate values of the factors.[3] Many workers have investigated the truth of this assumption, and their work demonstrates that for fast plates the error incurred in making it when dealing with the range of brightness encountered in street lighting work is not serious. The experience of the writer confirms their findings.

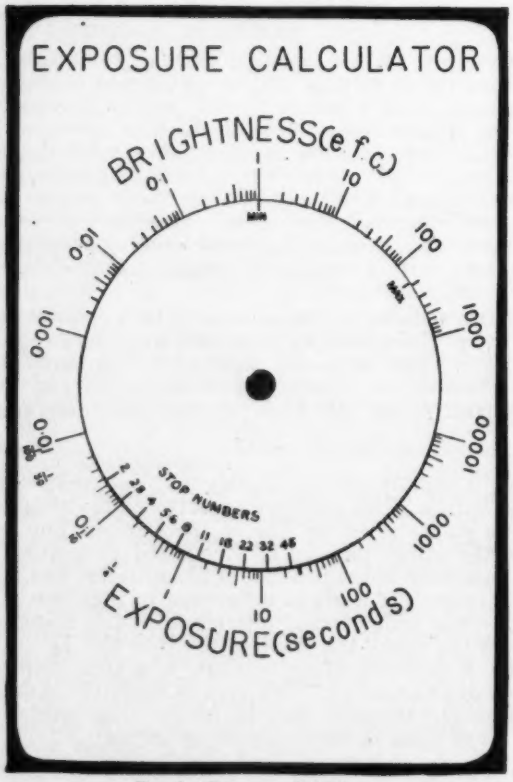


Fig. 5. Exposure Calculator.

The calculation of the time of exposure is quite simple in the comfort of the laboratory, but when working in the middle of a street on a cold night, errors are very liable to occur. A calculator has therefore been designed to perform the arithmetical part in determining exposure. A fixed dial carries scales of brightness and exposure, whilst on the moving dial are marks indicating the brightness range of the particular emulsion used and other marks indicating lens apertures. The range of any other emulsion can, of course, be engraved on the dial. In use, the brightness range of the street, having been measured, is found on the brightness scale and straddled by the plate marks. The correct exposure is then found opposite the appropriate lens aperture. (Fig. 5 shows the calculator adjusted as it would be for a brightness range of, for example, 2 efc. to 20 efc., indicating an exposure of 6 seconds at f.22. In appendix 3 data are given for the construction of an exposure calculator for use in pictorial photography.)[4].

The measurement of the maximum and minimum brightness of the subject can conveniently be measured with an instrument recently designed by J. M. Waldram for work on street lighting installations, a description of which is given in Appendix I.

An exposure meter which does not actually measure the brightness range is not suitable for street lighting photography. Photo-electric exposure meters are, therefore, not desirable. The exposure indicated by such a meter cannot be correct, because it does not ensure that the brightness range is rendered on the straight portion of the curve, but simply integrates the whole range of brightnesses, including that of the sources, and indicates a mean exposure. In any event, a photo-electric meter is not reliable because readings given at low brightnesses are not correct.

No allowance has been made in the calculator for the variation of plate sensitivity with the wavelength of the incident light. In the course of work over the past year, a very great number of photographs for photometric measurements have been taken on panchromatic plates with illuminants of different colours, and the densitometer records obtained from these plates have shown that no modification in exposure is required. It has not been considered necessary to examine, with any greater exactitude, the colour response of the materials used.

The wavelength of the incident light has some slight effect on the slope of the characteristic,[5] that is, that with the same after-treatment, a negative exposed to light of longer wavelength will be more contrasty than one exposed to light of shorter wavelength. A brief investigation into the effect has been made and is recorded in Appendix 4, where it is shown that the effect is so small that it is doubtful if the representation is materially improved by making compensation for it.

DEVELOPMENT.

The development given to a plate controls both the density and the contrast of the image. Increased development increases both density and contrast. Consequently, if a definite contrast is required, the development given must be standardised, and the density of the image cannot therefore be controlled by development (see page 20). The most satisfactory method of development for street lighting photography is the time and temperature method; and it is convenient to develop for a fixed time at a fixed temperature. If this is not always practicable, a time and

[3]F. Ross. Journal of Optical Society of America. 1920.

[4]See also Dow and Mackinney, Illuminating Engineer, 1911, for an interesting article on exposure.

[5]Dobson, Griffith and Harrison. Photographic Photometry. (Oxford. 1926.)

temperature table must be used. It is advisable for the photographer to draw up his own table for the developer and apparatus he uses[6]. Some notes on development are given in Appendix 2, which should be consulted.

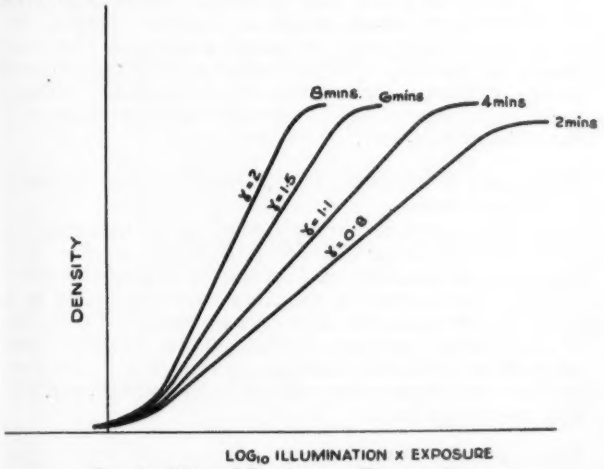


Fig. 6. Effect of Development Time on Contrast.

The effect of time of development on the slope[7] of the characteristic of the emulsion is shown in Figure 6. The slope of the characteristic determines the relation between the image density and the illumination, that is to say, the slope is a measure of the contrast of the negative, as has been shown previously. If the required contrast has been predetermined the correct time to develop to give that contrast must be found by plotting slope of characteristic (i.e, contrast) against time of development (see Figure 7) and from the resulting curve the required time found. For the system of representation under discussion it is convenient, but not necessary, for the slope to be unity, hence from the curve (Figure 7) we can find the correct time of development.

If the equipment necessary for determining this time is not available, the manufacturers of the emulsion used should be consulted.

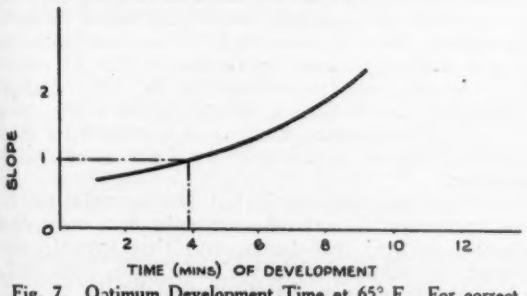


Fig. 7. Optimum Development Time at 65° F. For correct Contrast, slope of Characteristic = 1.

[6]A method is given in the Dictionary of Photography. (Iliffe.) See Appendix 2.

[7]The straight line portion of the characteristic can be expressed by an equation of the form:—$D = \gamma \log It + i$ where D = density, I = illumination, t = time of exposure. i and γ are constants. γ is the slope of the line.

CHOICE OF MATERIAL FOR PRODUCING THE NEGATIVE.

It follows from the considerations outlined and from convenience in working, that the chief points to bear in mind when choosing material are as follows:—

1. Speed. As fast an emulsion as is practicable from other considerations is desirable for street lighting work to keep the exposures as short as possible.
2. Freedom from liability to chemical fog.
3. Considerable latitude.
4. As uniform sensitivity as possible to all visible radiation.
5. Absence of objectionable grain.

Usually the faster an emulsion the greater the liability to chemical fog, so that an optimum speed depending on the tolerable fog must be found. Fast emulsions are usually of soft gradation, which is desirable. Fast emulsions also tend to graininess, but by using a fine grain developer and generally studying development, both chemical fog and graininess can be greatly diminished. Films or backed plates must always be used in street lighting work. If the emulsion has substantially the same sensitivity to all colours of the spectrum, no modification of the calculated exposure will be necessary when taking photographs of installations lighted by discharge lamps emitting coloured light. Hence it is essential to use a good panchromatic material.

There is now commercially available a good selection of fast panchromatic plates and films which combine the desirable properties enumerated above to a greater or lesser degree. It is recommended that a suitable material should be chosen and always used.

PRINTING.

A negative produced on the lines indicated should be a perfect reversed image of the subject. This negative must now be re-photographed to produce a positive image on paper. The same considerations which governed the production of the negative hold in the production of the print. The printing paper emulsion has a characteristic similar to that of the plate, but it is necessary to define the image density not as a function of the transmission but as a function of print paper reflectivity.

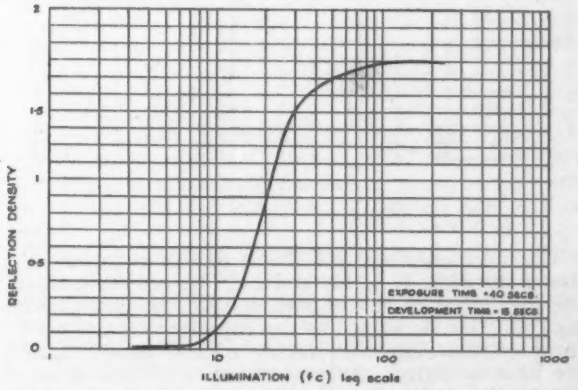


Fig. 8. Characteristic of Extra Vigorous Gaslight Paper.

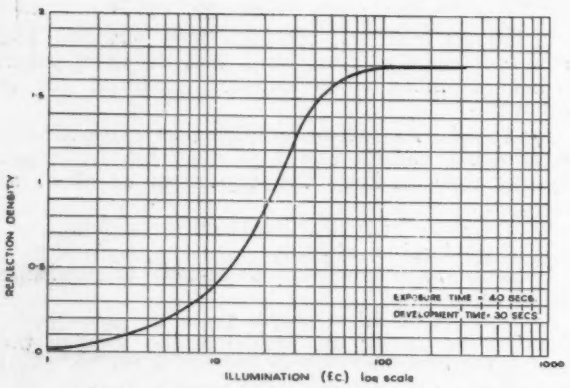


Fig. 9. Characteristic of Medium Gaslight Paper.

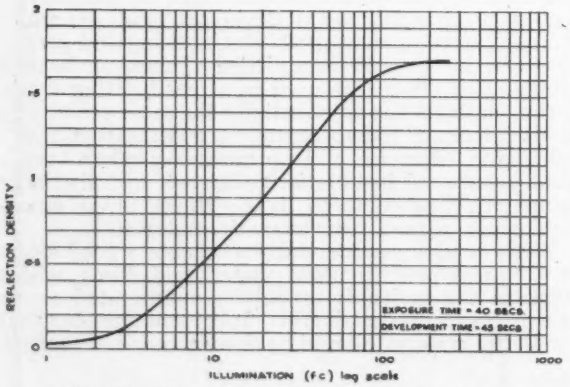


Fig. 10. Characteristic of Extra Soft Gaslight Paper.

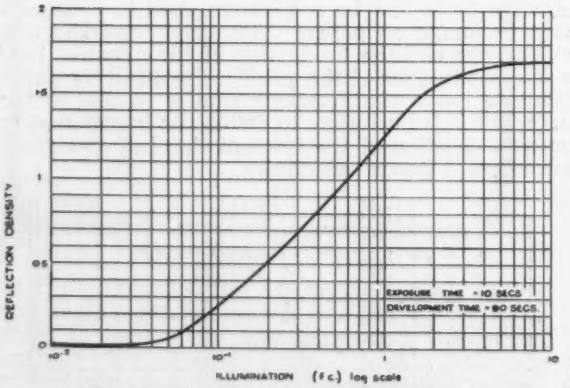


Fig. 11. Characteristic of Soft Bromide Paper.

The characteristics of some printing papers are shown in Figs. 8, 9, 10, and 11. The curves connect the logarithm of the exposure with the corresponding reflection density, i.e. the logarithm of the reciprocal of the reflection factor of the paper, taking the base as unity. A type of paper with a straight line portion to its characteristic is necessary, as otherwise the gradation of the negative will not be correctly reproduced on the print. The extra soft gaslight paper and the soft bromide paper which were examined, and whose characteristics are reproduced in Figs. 10 and 11, fulfil this requirement, for when fully developed both papers will give characteristics whose slope is unity. Hence, by printing or enlarging on these papers, in the way specified, the subject brightnesses can be reproduced in the correct ratio on the prints, and the second main requirement for correct representation will have been obtained.

Correlation between Paper Density and Subject Brightness.

Actual brightness cannot be spoken of numerically when discussing prints, for it depends on the illuminatior on the print and on the density of the print image. The former is variable, but the latter is a property of the print that can be specified. Hence a correlation between print paper density and brightness of the road surface is required. This correlation has been determined both experimentally and theoretically.

Experimental Correlation.

Ten representative installations were examined and photographs taken of each. The negatives were exposed and developed according to the principles outlined previously. From each of the ten negatives five prints were made, each rendering the contrast the same as on the street; but the five prints were of different overall density (see Fig. 12). Expert observers who knew the installations well were asked to pick out which of the five prints most nearly gave them the impression conveyed by the installation. This choice was made when comparing the installation with the prints from the same view-point as that from which the photograph was taken. The prints were judged by the loss of detail in the dark parts due to over-printing, by the gain of detail in the dark parts and the loss in the high-lights due to under-printing, and by the general impression given by the prints. The most accurate prints were chosen, and in the laboratory the print paper density of the areas of minimum brightness was measured. A curve was then plotted connecting these densities and the brightnesses they represented. The resulting relation was a straight line, as shown in Fig. 13. whose slope was calculated and shown to be 0.35. Further photographs of different installations were made using this scale, and in every case a true representation was obtained which withstood the most critical inspection.

These results suggested that the correlation had some fundamental basis. An investigation was made, therefore, to find this basis, and this investigation followed the principles which have been outlined in the introductory part of the paper

Theoretical Deductions.

The relation which has been mentioned in the introductory part of the paper, between the background brightness level to which the eye is adapted, and the corresponding lower limit of brightness visible, has

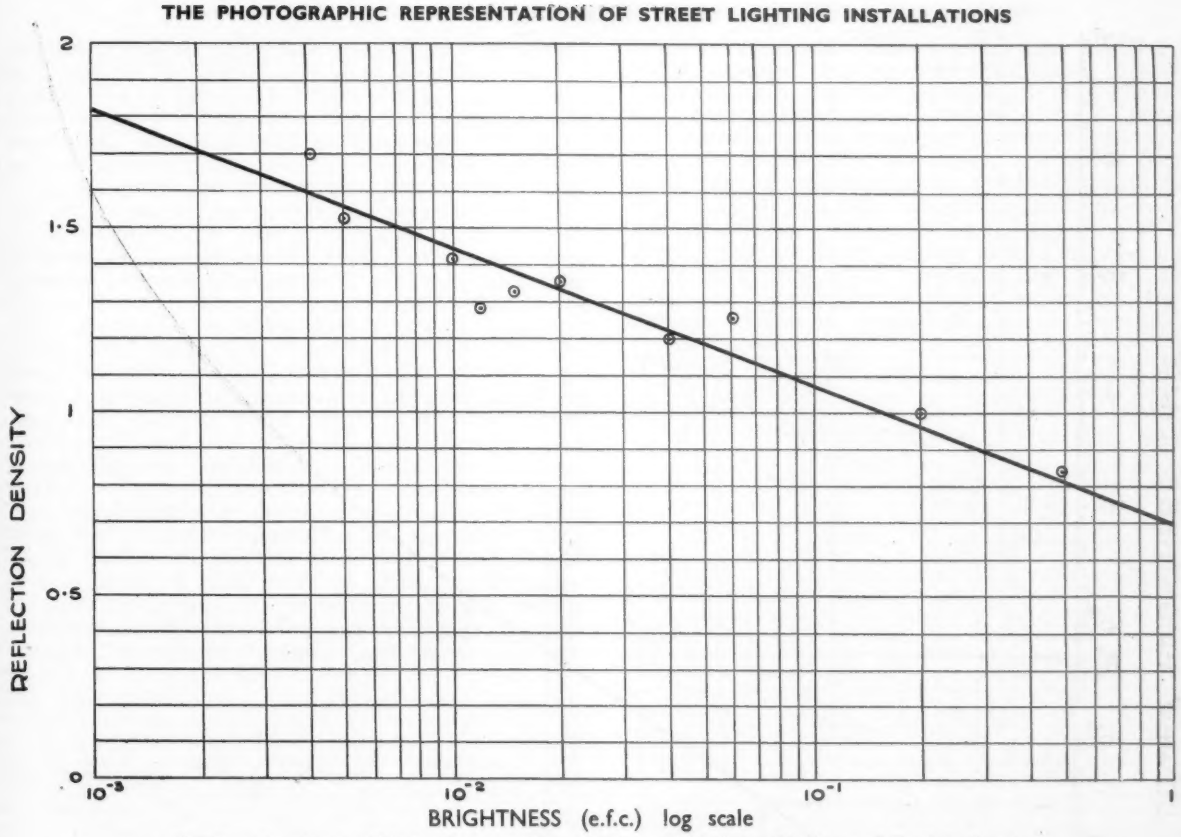


Fig. 13. Experimental Relation between Paper Density and Minimum Brightness of Road Surface.

been investigated by many observers, and a summary of their results is given in the curve shown in Figure 14[8]. This relation, when plotted on logarithmic coordinates, is represented by a straight line over the range encountered in street lighting work.

When a subject is viewed, the eye is adapted to a level of brightness which will be called the equivalent background brightness, B_{eq}. For a given value of background brightness (B'_{eq}). the corresponding lower brightness limit will be B'_t, as found from Figure 14. In a true representation photograph a brightness of B'_t should be represented by an area on the print of density such that when viewed under a given illumination, this area has a brightness equal to the lower limit corresponding to the eye adaptation level when looking at the print. The calculation of the numerical value of this density will be left until later. For the moment it will be called D_o.

Now consider a hypothetical photographic process which is capable of producing a positive print, on which the whole range of brightness which the eye can resolve at one level of adaptation, can be represented in the same ratio as on the subject. The relation between subject brightness and the density of such a print can be represented on logarithmic scales by a straight line of unity slope (Figure 15). From the assumption that a brightness of B_t must be represented by D_o, we know that one point on this line is (B_t, D_o), and hence the line is completely defined for any one value of B_{eq}. The density which should represent any other brightness can be obtained from this line, which we will call the print characteristic. For any other values of B_{eq} other print characteristics can be found which will be parallel straight lines of unity slope. From all of these lines can be determined the density corresponding to the value of B_{eq} for which they were drawn. In Figure 16 two such lines B'_tP', B''_tP'' have been drawn, and two points P′ (B'_{eq} D'_{eq}) and P″ (B''_{eq} D_{eq}″) obtained, giving the density at which the equivalent brightness should be printed. The locus of such points is a straight line correlating print density and the equivalent background to which the eye is adapted. The slope of this straight line is 0.34.

When an observer is viewing an artificially-lighted street surface, his eye is adapted to an equivalent background brightness which is a function of the various brightness values occurring in his field of view. Owing to the fact that there is rarely a large area of the street surface whose brightness is the same as the equivalent background brightness, the

[8] U. Bordoni, L'Elettrotecnica. Vol. XI. Sept., 1924. Nutting. J. Opt. Soc. America. 1920.

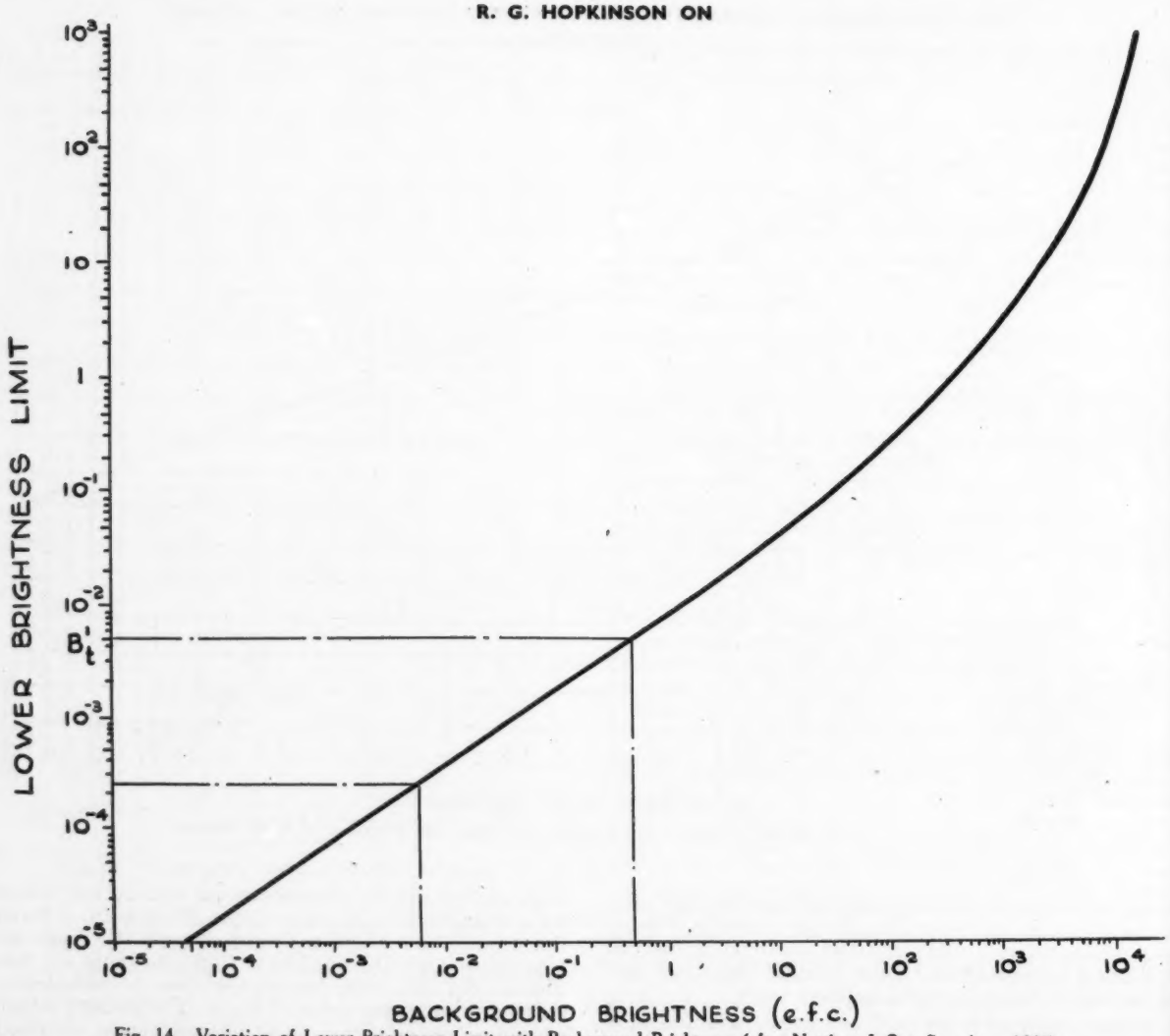


Fig. 14. Variation of Lower Brightness Limit with Background Brightness (after Nutting, J. Opt. Soc. Am., 1920).

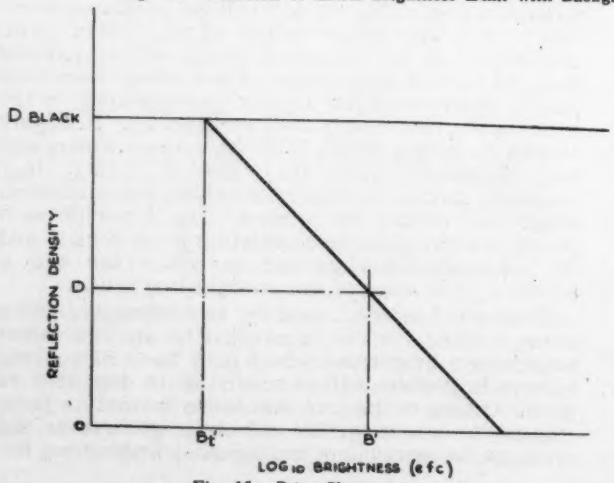


Fig. 15. Print Characteristic.

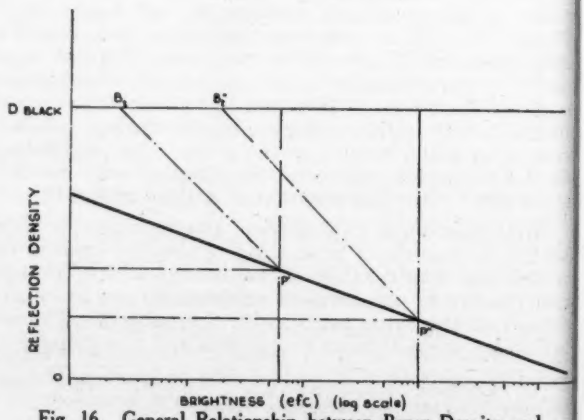


Fig. 16. General Relationship between Paper Density and Equivalent Background Brightness.

relation which we have obtained in Figure 16 cannot conveniently be used. We must, therefore, find a datum area on the street surface which is sufficiently large on the print for its density to be conveniently measured. The brightness of this datum area must be measured, and the density by which to represent it on the print found from the print characteristic corresponding to the equivalent background of the street surface. The area of minimum brightness on a street surface is usually large and conveniently situated for such measurement, as can be seen from Figure 23. The remarkable agreement between the slope of the relation between density and equivalent background brightness theoretically deduced, and the slope of the relation between density and minimum brightness experimentally deduced, suggested that some constant factor might connect the equivalent background and the minimum brightness of a street lighting installation. Measurements were, therefore, made on a number of installations, and it was found that there was evidence for the existence of such a constant factor. The average value of this factor for the installations examined was one fourth. If this factor of one-fourth be used, a theoretical relation can be obtained connecting minimum brightness and the density of that part of the print representing the area of minimum brightness. This relation has been derived in Figure 17 in the following way. P′P″ is the same line as in Figure 16. The points P′ and P″ correspond to equivalent backgrounds of B'_{eq} and B''_{eq}. The minimum brightness of a road surface whose equivalent background brightness is B'_{eq} is $\frac{B'_{eq}}{4}$, so the density by which to represent this brightness can be found from intersection of a perpendicular from $\frac{B'_{eq}}{4}$ with the print characteristic, giving a point Q′. Similarly for $\frac{B''_{eq}}{4}$ a point Q″ is obtained. The locus of such points is a straight line parallel to the previous line.

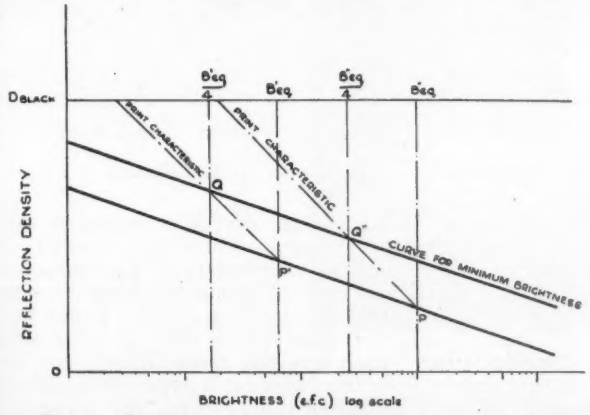


Fig. 17. Derivation of Density-Minimum Brightness Relation.

The actual numerical agreement of the theoretical and experimental results will depend on the value which is taken for the print density to represent the limiting brightness. When the sets of prints (Fig. 11) were examined, they were all illuminated to sixteen foot-candles, so that the eye would, in all probability, have been adapted to a brightness of 8 e.f.c. because the average reflection factor of the objects in the field of view was 50 per cent. The lower brightness limit corresponding to 8 e.f.c. is found from Fig. 14 to be .034 e.f.c., which would be the brightness of an area of the print having a density of 2.55. Hence this value of density would appear quite black if a print were viewed under 16 f.c. With this value of density as datum, scales can be inserted on Figs. 15, 16, and 17.

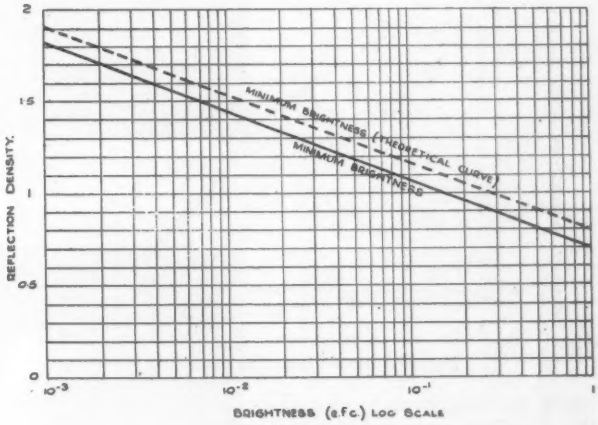


Fig. 18.

Fig. 18 (which is Fig. 17 re-drawn with appropriate scales), gives the theoretically deduced curve connecting minimum brightness with reflection density (shown in dotted lines). The experimentally deduced curve has also been reproduced on Fig. 18, and the agreement between the experimental and theoretical curves is seen to be good. In practice, the ratio of the equivalent background brightness to the minimum brightness, although of the order of four, will vary slightly according to the type of installation. It will be seen, however, that a variation of this ratio over quite wide limits will not materially alter the impression conveyed by the photograph if the average value of four is taken. Consequently the full curve of Fig. 18 can be used as the working correlation for the production of prints.

Although the photographic materials used cannot reproduce the complete range of brightnesses perceived by the eye at a given adaptation level, and particularly as low a density as 2.55, the representation given is far truer than might at first be supposed. Fig. 19 shows the actual overall characteristic of a street lighting photograph, which has been obtained by plotting subject brightness against print density. The street surface brightnesses are seen to be represented in the correct ratio, so that the greater part of the photograph is as it should be, but brightnesses which are much below the minimum street surface brightness are represented by too low a density, because of the failure of the print paper to give a density above 1.7. This does not greatly

detract from the value of the photograph, for the following reasons. The absolute lower limit as given by Nutting is a laboratory figure. In general, although detail is visible down to this lower brightness limit, it becomes vague at about ten times that

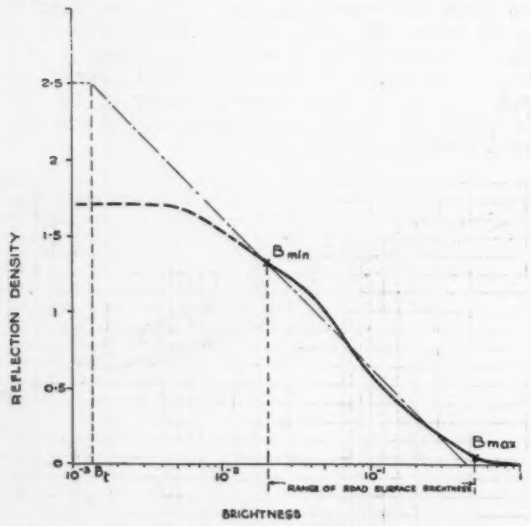


Fig. 19. Actual Print Characteristic.

limit, so that even if detail could be portrayed by the printing paper down to the limit, little gain in the perfection of the representation would be obtained. Although this detail would be represented on the print, it would be vague, as it was on the street, because of this characteristic of the eye. The effect would therefore be almost the same as is now obtained with ordinary materials.

Due also to the limited range of the paper, it is quite impossible to render correctly the brightness of the sources, and thus to show any effect they may have on the appearance of the installation. Here again it has been found that the truth of the representation is not affected in any important degree. If, for any particular purpose, it is desired to obtain an impression of the effect of the source brightnesses, the photograph can be viewed in the following way. The print is backed with black paper, and holes of the appropriate size are punched through the images of the sources. The photograph is placed above a background of such a brightness that the sources are of the correct intensity relatively to the brightness of the print. When viewed through a lens of the appropriate focal length, as perfect a photographic representation of an installation as can be expected will be obtained.

Production of Prints and Slides.

Production of Prints.

In order to facilitate the use of the standard density scale of Figure 13 when producing prints, a print exposure-density calculator has been constructed. This, as shown in Figure 20, comprises a fixed base A, with a small hole indicated by an arrow, a moving dial C consisting of a large number of graded density steps with a brightness scale corresponding to the curve of Figure 13, and finally an exposure dial B. The brightness scale on C is set so that the value of the minimum street surface brightness is opposite the

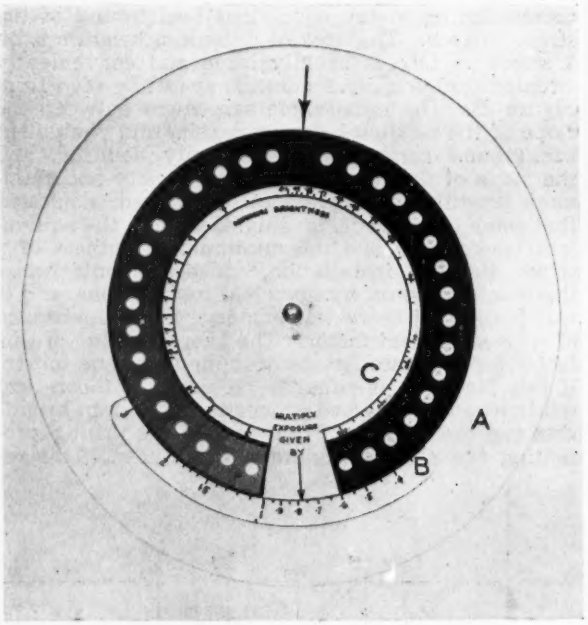


Fig. 20. Print Exposure-Density Calculator.

arrow on A. The exposure dial B is moved so that the arrow on dial C is opposite 1 on B. A and B are then fixed relatively to one another. The meter is laid over the datum area of minimum brightness on a trial print made on the correct grade of paper, and the dial C is moved about until one of the graded steps is found which has the same density as the datum area. Then the figure on B opposite the arrow on C indicates the factor by which the exposure given to the trial print should be modified to give the final print.

Production of Lantern Slides.

The standard density scale can be directly applied to the production of lantern slides. A lantern slide emulsion which gives the correct contrast is of course used. The transmission density of the slide must be the same as the reflection density of a print in corresponding parts.

The density of the slide is best measured by a suitable type of densitometer. It is also possible to make reasonably accurate determinations with the print density calculator already described. The lantern slide should be held above a white surface whose reflection density is 0, and the calculator placed over the datum area, so that it receives the same illumination as the white surface. For a correctly printed

Fig. 1. A True Representation of a Street Lighting Installation. (Viewing Distance = 5″.)

Fig. 2. A Print of Too Great a Contrast.

Fig. 3. A Print of Too Great a Density.

Fig. 12. Prints of Graded Density.

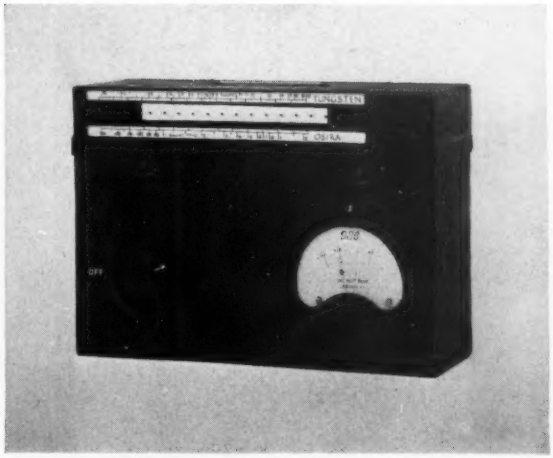


Fig. 25. Brightness Meter.

Fig. 23. Position of Max. and Min. Brightness on a Street Surface. The area of min. brightness is usually large and in the foreground of the photograpn.

Fig. 24 (a). Brightness Meter reading Maximum Brightness on a Street Surface.

Fig. 24 (b). Brightness Meter reading Minimum Brightness on a Street Surface.

Fig. 28. Lombard Street, London, E.C. (Viewing Distance = 21".)

lantern plate, the datum area should appear of the same brightness as the step of the calculator whose density corresponds to the datum brightness in the street.

Lantern slides can only give true representations when projected by a beam of sufficient intensity to provide adequate illumination on the screen. The screen illumination when no slide is in the lantern should not be less than six foot-candles.

Stray light may completely spoil the effect. Correct perspective is difficult to obtain with projection, and it should be fully realised that in practically every case a projected lantern slide subtends only a fraction of the correct angle at the eye.

Illumination on Prints produced in conformity with the Standard Density Scale.

The reason why a standard print will give good representation over a wide range of illuminations can be deduced from Fig. 14. This curve, which connects the lower limit of brightness visible with the background brightness, can be replotted as a connection between the upper limit of density, which will appear quite black, and the illumination on a print. This has been done to give Fig. 21, where an average reflection factor of the field of view of 50 per cent. has been assumed.

It will be seen that this density is reasonably constant between 5 and 1,000 foot-candles, and the value taken when drawing Fig. 18, (D = 2.55 at 16 foot-candles), is seen to be an average value.

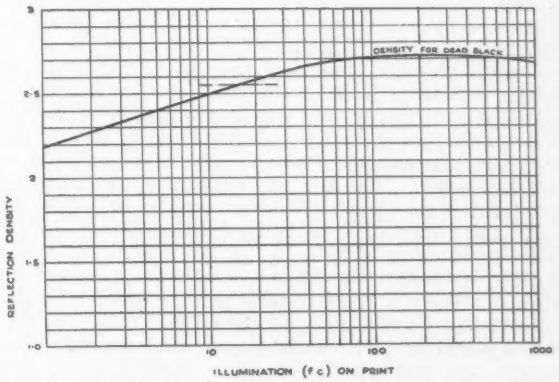


Fig. 21. Relation between Reflection Density and Illumination.

Photographs for Reproduction.

A short investigation was made to find whether the faithfulness of reproduction was affected by reproduction by photo-mechanical processes.

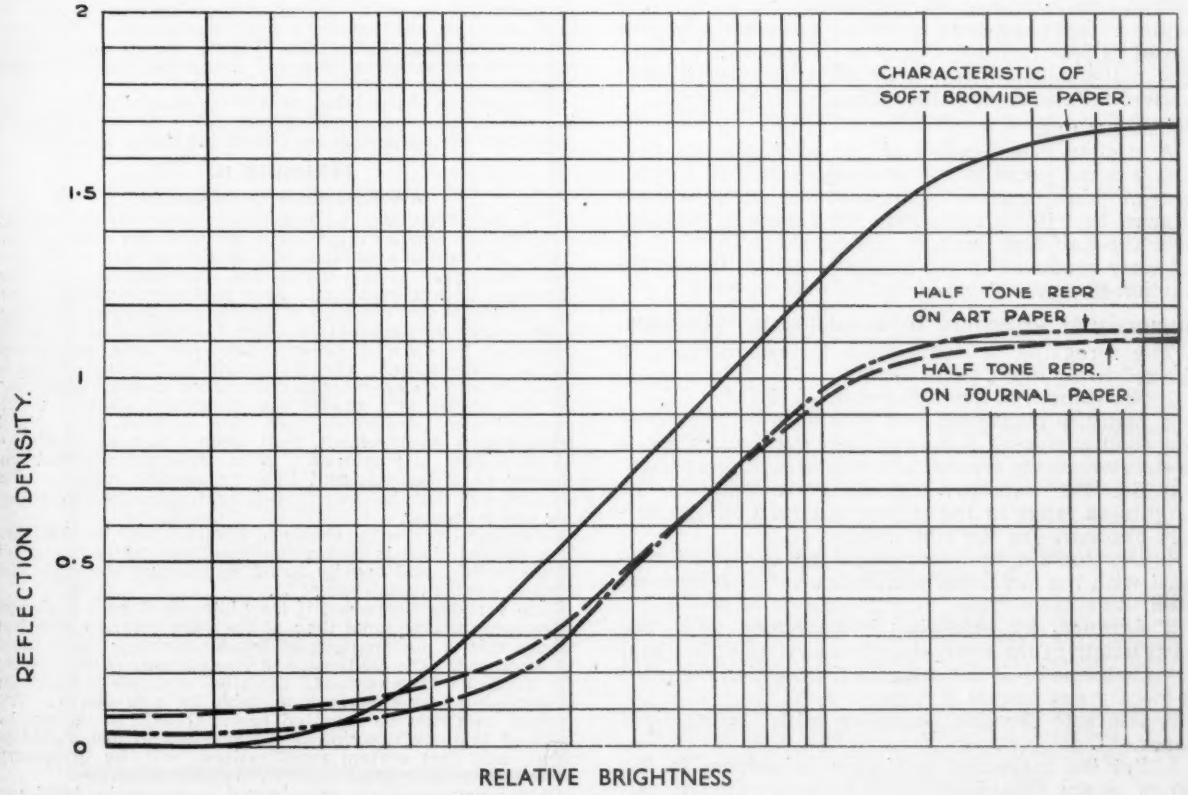


Fig. 22. Effects of Half-Tone Reproduction.

HALF-TONE REPRODUCTION.

The curves (Fig. 22) show the effects produced by half-tone reproduction. Curve (a) is the relation between reflection density and illumination on the paper for a soft bromide paper. The curve was obtained by printing through a calibrated step-tablet divided into twenty strips, and measuring the density of each strip of the resulting print. A half-tone block was then made of the print, and pulls taken on art-surfaced paper and on good quality newsprint. The reflection densities of the corresponding steps were measured, and from these curves (b) and (c) were drawn. The curves show that although the contrast is not greatly altered by the half-tone process, the range of density is shortened considerably. The shortening of the range of density is caused, firstly, by some ink always printing out in the high lights, although the primary print is white in those areas and hence the density of the white parts is 0.08 against 0.0 on bromide paper; and, secondly, good blacks are not obtainable, the highest density on journal paper being 1.1 against 1.7 on bromide paper. The half-tone reproduction can, therefore, record faithfully a brightness range of only 10-1 against 50-1 on gaslight and bromide paper. The contrast is therefore destroyed over part of the range, the high lights and the shadows clogging up. Over the middle of the range the contrast is nearly the same as on the primary print.

Fuller investigation has not been possible, but it is evident that half-tone printing as commonly produced is less faithful than the photographic print. The half-tone illustrations in this paper are subject to the limitations described above.

PHOTOGRAVURE.

A similar investigation of the photogravure process was not possible, but an examination of a number of high quality photogravure reproductions showed that this process may have some advantages over the half-tone process. Densities of from 0.1 to 1.8 were produced in the illustrations but the reproduction of contrast could not be determined.

Summary of Procedure Involved in the Technique.

The foregoing procedure can be summarised in the following eight steps:—

1. Set camera at average eye-level (5 ft.).
2. Measure maximum and minimum brightness of the road surface. Note carefully, preferably on a sketch, where the area of minimum brightness occurs.
3. Set the exposure calculator to straddle the brightness range of the street, and read off the correct exposure for the stop used.
4. Develop for the time which gives correct contrast with the developer and method of development used.
5. Arrange, by enlarging if necessary, that the focal length of the equivalent lens system of the final print is the same as the distance from which the print is to be viewed.
6. Use soft bromide paper or extra soft gaslight paper.
7. Set the measured minimum brightness to the arrow on the fixed base of the exposure-density calculator. Set the exposure scale on 1.
8. Make a trial print, noting the time of exposure and developing fully. Place the calculator over the area of minimum brightness on the print, and find the modification necessary to the exposure. Using this modification, make the final print.

The technique of the photographic representation of street lighting installations has been fully described. Fig. 28 shows a half-tone reproduction from a photograph produced by this technique. It shows, within the limitations of the half-tone reproduction of the original print, that photography, far from being, as hitherto, an unreliable guide to the illuminating engineer, can be one of his most valuable aids.

In conclusion, the author wishes to acknowledge the help rendered by the Research Laboratories of Messrs. Kodak, Limited, by the Ilford Research Laboratories, and by Mr. J. S. Dow in the conduct of the investigation.

APPENDIX I.

Measurement of Brightness.

Figure 23 shows a photograph of a street, the crosses marking the positions of maximum and minimum brightness of the street surface. The brightness meter, as can be seen from the photograph (Figure 25), consists essentially of fifteen silvered spots in a field of clear glass placed at 45 deg. to a translucent screen illuminated from one end. These fifteen spots will therefore be of brightness decreasing from the brighter end of the screen. The street is viewed through the glass field, and the meter moved about until one of the spots disappears, or nearly disappears, against the background of the part of the street whose brightness is required. The meter is calibrated to read equivalent foot-candles (e.f.c). The two photographs (Figures 24 (a) and 24 (b)) show the meter measuring the maximum and minimum brightness of the street shown in Figure 23.

The position of the datum area of minimum brightness can be seen in the photograph (Figure 23). It usually occurs quite near the camera, at the side of the street, as shown.

APPENDIX II.

Investigation of Development.

The manufacturers of photographic materials are usually willing to provide information about optimum development time. If there is apparatus available, it is both preferable and instructive to investigate the characteristics of the developer and method used. Four plates or films are given the same exposure behind a calibrated stepped optical wedge under a known illumination. The four plates or films are developed for different times, at the same temperature and by the same process. The characteristic of each emulsion is next obtained. Care must be taken when measuring density, for the scatter will render the measured density much greater when parallel incident light is used, and direct transmission measurement, than when a method of diffuse incident light is employed. It is recommended that the method of diffuse incident light be used to measure the density, and that the same type of lighting be used for printing and enlarging.

A series of curves, as shown in Figure 6, will be obtained. The desired time is that which produces unity slope of characteristic, and can be found by plotting slope against time of development (Figure 7).

One variable is avoided if the plates or films are always developed for the same time at the same temperature, but where this is not possible, a time-temperature table must be employed. The Dictionary of Photography (Iliffe), under the heading "Development," describes a simple method for determining a time temperature table for a developer. The method need not be repeated here. It will, of course, be realised that the description there refers to dish development, and that certain modifications will be necessary according to the method used by the investigator.

If the negative is to be enlarged, a fine-grain developer is, of course, desirable. Otherwise a standard developer

recommended by the manufacturer for the plate being used should be suitable. If very fast plates are used, more care is needed in the choice of developer because of the greater liability to chemical fog and graininess. This is a matter for experience to decide. Generally it has been found that less fog is produced if a strong developer acts for a short time than if development is prolonged and a weak developer used.

It is worth while taking precautions to obtain evenly-developed negatives. It is always desirable to keep the developer continuously moving over the surface of the plate. This is effectively done, as suggested by Dr. W. Clark, by brushing the plate surface with a soft wide camel hair brush. A clean deep dish, larger than the plate, should be used, and plenty of developer is preferable.

The method of development alters the time for correct development at a given temperature, and hence the photographer must draw up his own temperature time table, unless he uses exactly the same procedure as the publisher of the time table he wishes to use. Dr. Dobson has suggested to the writer that the time of development is affected by two considerations: firstly the time for fresh developer to diffuse through the stale developer in the emulsion, this time not being affected by temperature; and secondly the time occupied in actual chemical reaction, which is affected by temperature. If the first time is decreased by forcing the stale developer away from the emulsion, the effect of temperature on the time will be greatly increased.

APPENDIX III.

Construction of Exposure Calculator.

The fixed dial of the calculator has two similar logarithmic scales, one of brightness in equivalent foot-candles, and one of exposure time in seconds, at opposite sides of the dial. The moving dial has stop marks engraved on one part of its circumference. The relative exposures necessary to give the same results with these stops determines their distance apart. Thus the exposure for f.11 is half that required for f.16, so that the distance apart of these marks is that which represents x2 on the logarithmic scale used for exposure.

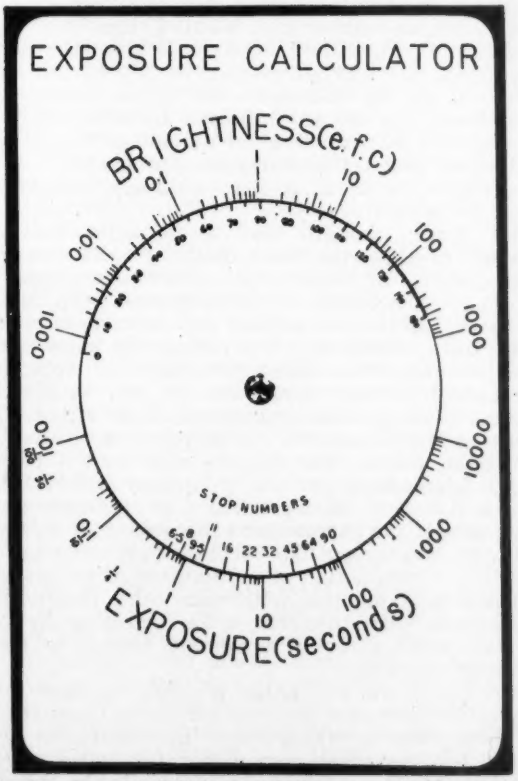


Fig. 26. Exposure Calculator with degree scale. The straight line range of an emulsion can be expressed on the degree scale.

The following considerations apply when marking the range of a plate or film emulsion on the calculator. A brightness of 1 efc. when photographed through a lens of 100 per cent. transmission, whose aperture is f.11, produces an illumination on the emulsion of 0.0065 foot-candles. The average transmission of most lenses is of the order of 60 per cent., so that the effective conversion factor is 0.004. The straight line range of the emulsion, measured in foot-candle seconds, should be obtained from the manufacturers of the plate or film to be used. Suppose this range is from 0.002 fcs. to 0.2 fcs. Dividing these values by 0.004, the conversion factor for f.11, the brightness range at f.11 is seen to be from 0.5 efc. seconds to 50 efc. seconds. Setting the calculator so that the f.11 mark is opposite the 1 second mark, the range of the plate can be marked in from the brightness scale, the minimum mark being made opposite 0.5 efc. and the maximum mark opposite 50 efc.

Figure 26 shows a scale marked in degrees of arc which can be substituted for the plate marks. When the calculator is set for f.11 to be opposite 1 second, the zero of the scale is on 0.001 efc. The range of various emulsions can now be expressed in terms of these degrees, preferably in the form of a table to be used in conjunction with the calculator. Such data could be supplied by the plate or film manufacturers.

APPENDIX IV.

Effect of Colour of Light Source on Contrast.

A very brief investigation was made to find what effect the colour of the light source had on the contrast. A plate was exposed behind a step wedge three times the exposure (illumination x time) being the same in each case; but the light source was a tungsten filament lamp in the first case, a sodium vapour lamp in the second, and a high pressure mercury vapour lamp in the third. The plate was then developed by the standard method, and the relation between exposure (on logarithmic scale) and density plotted for each type of light source. The results are shown in Figure 27.

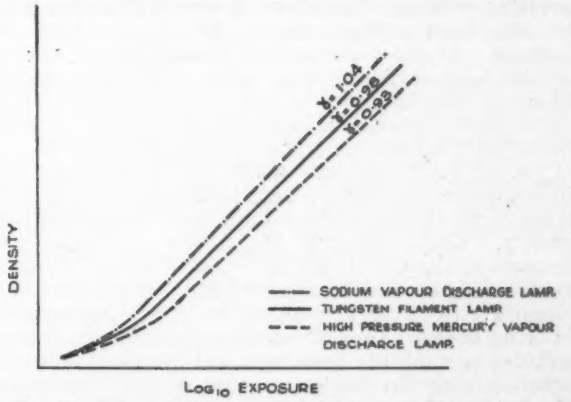


Fig. 27. Effect of Colour of Light Source on Characteristic of Panchromatic Plate.

The source emitting light of longer wavelengths (sodium vapour) gives a slightly higher contrast than that emitting shorter wavelengths (mercury vapour), but the difference is quite small. The alteration in development time necessary to compensate for the effect could be obtained from Figure 7; but as the variation in contrast is within the limits of accuracy of the method of development, it is doubtful if much would be gained by making this correction.

The correction factors as obtained from Figure 7 are:—

Tungsten filament lamp	1.
Sodium vapour lamp	0.9.
Mercury vapour lamp	1.1.

DISCUSSION

Mr. G. H. WILSON (General Electric Research Laboratories) said it had been as great a pleasure to hear this paper as it had been to co-operate in a small measure with the author in his experimental work. The problem which had been dealt with was a very urgent one to illuminating engineers, and the need for a solution was therefore more evident to them than to photographers. From the street lighting point of view visibility was a function of the contrast existing, and as a rule in street lighting installations distant objects were seen as dark against a light background. Nearby objects were often seen by internal contrast, and the photograph gave an excellent method of recording the effectiveness of various backgrounds and of the internal contrast which existed, providing it gave a reliable record of the original installation. Moreover, he believed the photograph helped in the interpretation of a very common remark often heard amongst laymen, viz., that for good visibility he liked uniform or even lighting. That, however, was not a simple matter for the illuminating engineer to interpret; but when one looked at a photograph it was possible to realise that what the average man wanted was a uniform road surface without any dark patches in which no object could be seen. Perhaps one unfortunate feature of the work described by the author was that the process was not applicable to half-tone reproduction. The author, however, had called attention to the limitations which existed when the endeavour was made to reproduce an original photographic print by some printing process. Therefore, it would be interesting to hear from any process workers who might be present. At the same time, from the little he knew on this subject there did not seem to be much chance of being able to apply this process to reproduction. Mr. Wilson expressed his appreciation of the improvement that had been made in photographic materials in recent years, without which the work described in the paper would have been impossible. The knowledge of these improvements, however, had made him greedy. Quite recently, Mr. Smith and some colleagues of the Gas Light and Coke Co., and Messrs. Davies, Lucas, and Maxted, of the B.T.-H. Co., had taken a cinematograph film from a moving vehicle in order to study the various backgrounds which contributed to visibility in streets; but the film had to be taken during the day on account of the limitations of photographic materials. It would be most valuable for the illuminating engineer to have a cinematographic film taken at night from a moving vehicle at normal speed according to Mr. Hopkinson's technique. If the illuminating engineer were given that one thing more, he would be quite satisfied.

Mr. F. C. SMITH (*communicated*) said that it was with great regret he found himself unable to be present at the joint meeting of the two Societies. He would sincerely like to congratulate Mr. R. G. Hopkinson on carrying out an extremely interesting and useful piece of work and to thank him for the lucid manner in which he had described his work in the paper that evening. He noticed in the introduction to the paper that Mr. Hopkinson said it had been the cause of general comment, voiced by authors of recent papers on street lighting, that street lighting photographs were quite unreliable as a means of studying the characteristics of an installation.

Mr. Smith then referred to a paper dealing with visibility under street lighting conditions presented to this year's conference of the Society of Public Lighting Engineers and prepared by Mr. Sawyer and himself, and said that they must plead guilty of expressing the view that some photographs of street lighting installations were entirely unreliable guides to the merits of the installations. During the delivery of this paper these points had been illustrated by showing four slides of photographs taken of a street in Westminster, and it would help those present to decide whether their condemnation of uncontrolled photography as a means of appraising street lighting installations was justified if he could be allowed to put these photographs on the screen. Mr. Smith then showed three photographs all of which were taken from the same position in the road, but the times of exposure in the street were in the ratio of 1 : 3 : 9. Each plate was subjected to identical treatment in the dark room. Mr. Smith drew particular attention to the difference in brightness of the appropriate backgrounds. In the first case one might suppose one were looking at an old fashioned installation; in the second case at a modernised version of the first installation; and in the third case at an installation certainly superior to what one would associate with a Class A installation.

Mr. Smith thought they would agree that any attempt to judge the value of the installations from photographs of that kind would be open to the gravest criticism. It would have been foolish, however, had they stated that photographs were of no value, since in their own experience they knew it to be possible under controlled conditions to reproduce photographs which were more or less satisfactory records of the general appearance of the street. The fact that Mr. Hopkinson was doing work on the lines he had described that evening was known to Mr. Smith when the paper was published and Mr. Hopkinson had very kindly taken a photograph of the same street. On examination this print had indicated that Mr. Hopkinson had succeeded in securing an excellent reproduction of the lighting of the street.

These facts, together with many other instances he could quote, were justification for regarding the work of the author as being extremely useful to street lighting engineers.

Mr. Smith did not know whether he dare make any reference to the pictorial effects so often accompanying trade advertisements in connection with street lighting; those responsible for those advertisements so often portrayed a picture in the street as they would *like* to see it rather than as it really was

seen. Those most competent to speak in the advertising world are agreed that truth is a virtue in advertising which has very high commercial value.

Mr. Smith then put on the screen a fourth slide which again was a picture of the same road from an *untouched* negative showing what an ideal installation this type really was. The high road brightness that they could see on the screen before them was the product of the judicious use of thin tissue paper before the enlarging camera, and it was to be noted that the slide was made from the same negative as that of the first slide shown. He thought that they would agree that manipulation of that kind was to be condemned in advertising matter; it certainly had no place at all in technical photography.

Mr. Smith had hoped to produce for the meeting a photograph in accordance with the method given by Mr. Hopkinson, but could say, however, that calibration work of the type referred to was already in hand by their own Photography Section. Mr. Hopkinson would have done a real service to all illuminating engineers if those concerned agreed to use a method developed along the lines suggested by the paper before them that evening.

In the British Standards Institution Specification for street lighting it was recognised that horizontal illumination or brightness measurement were but substitutes for some scale of visibility which up to the moment had not been developed. Was it too much to hope that a controlled photographic method might provide a stride forward in the solution of that difficult problem? He thought that Mr. Hopkinson was a trifle optimistic as to the ease and accuracy with which one could measure general brightness levels on the street, especially under wet conditions. It might be urged that a wet night was an unsuitable night to make a photograph, but since streets had to be used when wet the public lighting engineer was vitally concerned with visibility under wet conditions as well as under dry.

There was one further point to which he thought sufficient treatment had not been given in the paper. It was rather doubtful whether photography would ever enable us to record such disturbing subjective influences as disability and discomfort glare; the point was illustrated in the slides which had just been shown. At the end of the road they would recall that they had seen a shop on which the name was visible on the slides, but in the street, however, this name was not visible on account of glare effects.

In conclusion, in spite of the drawbacks he had referred to, there could be little doubt that Mr. Hopkinson had made a real contribution to the technique associated with street lighting.

Mr. F. F. Renwick (Ilford, Ltd.) remarked that perhaps it might serve a useful purpose if he tried to give his impression of what this paper did for photographers. No doubt there would be some anxious to cross swords with the author, but the consideration of details should not be allowed to obscure the fundamental importance of the contribution which the author was making to the whole problem of realistic photography. Although the paper was primarily concerned with the faithful reproduction of artificially lighted road surfaces, the principles enunciated appeared to be applicable to the solution of the much wider problem of faithful rendering by photography of any scene. Such problems had been discussed times without number before the Royal Photographic Society, but they had never yet succeeded in persuading their pictorial brethren to adopt scientific methods. At the same time, it must be confessed that little real effort has yet been made to discover the underlying scientific principles which prompted the pictorialists' preferences and practice. The author claimed to have discovered experimentally, and verified theoretically, a new rule relating to realistic reproduction in night photography, and he felt that what the author had done was really in accord with the practice of the best exponents of photographic art. His rule is to employ such a density value in the print for the darkest tone present in the subject that all deeper tones that would have been distinguishable if they had been present could also have been satisfactorily rendered and discerned in the print. The important advance made by the author, however, is in discovering the relation between these darkest tone values as measured and the appropriate print densities to give them in the print when the general brightness of the scene depicted varies from case to case. Here may I inquire whether I am not right in thinking that the slope of the line 0.35 in the graph embodying this result is simply a direct consequence and expression of the relation between the equivalent background brightness and the range of tones discernible below that background level as given by plotting the differences log B_{eq}—log B'_t against log B_{eq}.

The author states, without, however, giving figures, that the range of brightness that the eye can perceive at any one moment is limited. I was under the impression, however, that this range is more than 1,000:1 and greater than can be recorded on any flat white reflecting surface, even with the blackest pigments we possess, and far greater than that of any photographic process. In this country the atmosphere is rarely so free from haze or dust that we get the opportunity of seeing all there is to be seen of an interior through an open doorway.

For this Society and for the general body of serious photographers the chief interest of the paper will centre round the question whether their methods have a general application, for it is clear that in some important respects current practice differs widely from theirs, and I look forward with considerable interest to the future discussions which this paper will evoke. A very small proportion of pictorial photographs comply at all closely with the principles so frequently advocated by those who have given attention to the underlying scientific principles of photography in the past from the days of Hurter and Driffield onwards, and it is not likely that any rapid change will be brought about by this paper; but it affords us the opportunity of reopening the question with a better understanding of certain points which have hitherto evaded a proper scientific treatment.

If time permitted there are several points I should like to discuss, e.g.:

1. The influence of the shape of the shoulder of the characteristic curve of the paper and the foot of the negative characteristic on shadow detail rendering.
2. Within the total range of brightnesses of, say, 3,000:1, which the eye can appreciate at a given moment, there is a change in apparent contrast from tone to tone in a uniform scale of tones. Are these differences of contrast at the two ends of the scale of sufficient importance in practical photography to require attention?
3. Whether there is any advantage to be gained by using both negative and positive materials having a gamma of 1, over two materials matched to give a combined product of 1.
4. Whether a photo-electric photometer is satisfactory for determining values of equivalent background brightness accurately.
5. It seems possible that the level of adaptation of the eye in presence of strong light sources may be very different from equivalent background brightness degree of adaptation. What evidence has the author on this point?
6. Lastly, there is the big question of how far in the direction of higher illumination levels Mr. Hopkinson's graph connecting minimum brightness and print density can be extrapolated with satisfactory results, and what different relationship must be substituted for it when it breaks down, as it evidently soon must do.

Before I sit down I should like to tender to the author my sincere admiration and thanks for his valuable contribution to a subject which has always had a great interest for me.

Mr. E. R. DAVIES (Superintendent of Research, Kodak, Ltd.) agreed that this paper struck at some of the fundamentals of photography, and he congratulated the author on the sporting way in which he had come to the Royal Photographic Society—the home of photography—and expounded his solution of this problem. There was little doubt that the author had challenged photographers in that he claimed to have solved a problem which they were far from claiming to have solved for themselves. Indeed, he would go so far as to say that if the author had come to the photographers before he had started and asked for their advice, he would have been told that his task was impossible. Instead of this, he had tackled the problem for himself and had hammered out what appeared to be an extraordinarily simple rule for the production of photographs that are subjectively correct, and he had submitted evidence which showed that by this means he was able to obtain photographs that were very excellent for his purpose. The question of interest photographically was to what extent the rule could be applied more generally. Did it mean that, if a number of subjects were photographed and their equivalent background brightnesses measured, it would be possible to make correct prints merely by following this rule? Take, for instance, a landscape photographed on a sunny day and also on a dull day. Let it be assumed that for each the equivalent background brightness was the average brightness of the scene. Was it necessary only to measure this average brightness in order to know exactly how to make the prints? If so—and this was simply a logical consequence of the idea extended to the realm of ordinary photography—then all he could say was that a new use had been found for photo-electric exposure meters, because they could be used not only for the purpose of judging the exposure of the negative, but also for determining the average density to which to make the print. Owing to the very restricted range of tones that it is possible to reproduce on paper, a strict following of this rule would often mean a loss of detail in parts of the picture. The photographer, he felt, might be prepared to make sacrifices in other directions in order to obtain detail in the high lights and in the shadows which might be missing if this method were adhered to, and so, for this reason, might deviate from the rule.

Mr. Davies went on to describe at length some recent work of his French colleague M. Abribat (Science et Industries Photographiques, 6 Series II,. June, 1935, pp. 177-182), which deals with an attempt that has been made to measure the visual sensation curves for different adaptation conditions. From these, he said, he hoped to reveal more clearly the assumptions underlying Mr. Hopkinson's theoretical deductions, so that it might become possible to determine how generally his rule might be applied. If the sensation curves appropriate respectively to the viewing of the installation and to the viewing of the print are known, it becomes possible to deduce the exact relationship that should exist between the brightness of the subject and the density of the corresponding part of the print. By means of lantern slides depicting data taken from M. Abribat's paper, he showed that Mr. Hopkinson's deduction that the best result is obtained when this relationship is represented by a straight line of unit slope implied that the sensation curves must be either parallel or identical. Because of the difference in the adaptation conditions they could not be identical, and M. Abribat's experimental results indicated that they could only approximate to being parallel over a very limited range. For this and other reasons, he felt that the theory advanced by Mr. Hopkinson could be little more than a rough approximation to the truth over a very limited range and could not, therefore, be of great value in solving the more general problems of photographic tone reproduction.

One point in particular in the experimental part of the paper seemed to him to be open to criticism. According to the experimental evidence, if Mr. Hopkinson's rule were followed, one obtained a print which was judged by an observer to represent accurately the appearance of the installation when it was illuminated to a standard level *and viewed on the*

installation. Could it be assumed from this evidence that two photographs of different installations would always truly represent the two installations when they were viewed side by side in a room? Under these conditions, the adaptation of the eye would be the same for both prints, while it might be widely different when viewing them on the installations; for then the adaptation conditions would be largely governed by the installations themselves. In this connection, he was very interested in Mr. Hopkinson's remark, that "*it is a peculiar trick of the memory which causes one's recollection of an installation to be flattering to the installation, so that a 'true representation' photographic print will almost always appear darker than one would expect. This should be borne in mind if any disappointment should be felt when first seeing such a photograph.*" Was this effect really the result of an imperfect memory or was it real, implying a shortcoming in the method due to this difference in adaptation levels? An experiment that might be worth trying would be to place the prints for viewing at the end of a darkened box, and to illuminate them in some convenient way, so that one could be sure that the adaptation of the eye would be the same when viewing the prints on the installation, and when viewing them afterwards in comparison with prints of other installations. Would such an arrangement lead to the selection of the same prints as being the best obtainable?

Mr. J. M. WALDRAM (General Electric Research Laboratories) said the author was to be congratulated not only upon his results and upon the successful connection between his experiments and the results given by Nutting, but that he had shown what a simple matter it was to put his method into effect with the help of straightforward calculators. At the same time, no doubt, the author would agree that there was no system in existence, and probably never would be, which gave what could really be called a truthful picture. He felt that the author's results were useful in the same sense as "true to scale" prints of drawings were useful, in that no significant error resulted from their use for the purpose for which they were intended. In both these photographs and in "true to scale" prints, refined measurements would doubtless detect errors; but they were not sufficient to impair their usefulness as records.

He was particularly interested in the author's mention of the well-known effect of a lens in viewing prints. It seemed probable that the impression of distance and of reality was brought about by the interaction of several factors simultaneously; for instance, the effects of perspective, mist, and parallax, as objective factors, and of accommodation, convergence, and stereoscopic effect as subjective factors. For a really exact impression to be conveyed all these factors should be correct; the lens device, using one eye, corrected several of them directly, and others by implication.

He asked Mr. Davies whether Abribat's method was similar to one suggested by Nutting in which the sensation curve was obtained by an integration of the contrast sensitivity curve. He believed that the validity of this method had been questioned.

MR. E. L. DAMANT said that he had spent a good deal of time looking at street lighting installations, and was therefore able to appreciate the work done by the author.

At the same time he doubted whether the author himself would claim that a photograph could give an absolutely true reproduction of one's sensations on a street. Mr. Davies had mentioned a point to which he himself intended to refer, namely, "the trick of the memory." After all, things were what they seemed, and if one looked at a photograph and it did not give the right impression, it was not very helpful to be told that if one went out into the street and looked at it under those conditions it would do so, because it had then lost its value as a pictorial record. Other speakers had pointed out that photographic prints could not reproduce the effects of source brightness or of parallax due to slight movements of the observer, and he imagined that stereoscopic effect and general background brightness (peripheral vision) whilst viewing the photograph were other missing factors.

Moreover, it appeared that an observer viewing the prints needed arrangements to ensure the correct angular subtense of objects at his eye and the correct state of accommodation of his eyes if the claim of perfect reproduction of the street scene was to be substantiated.

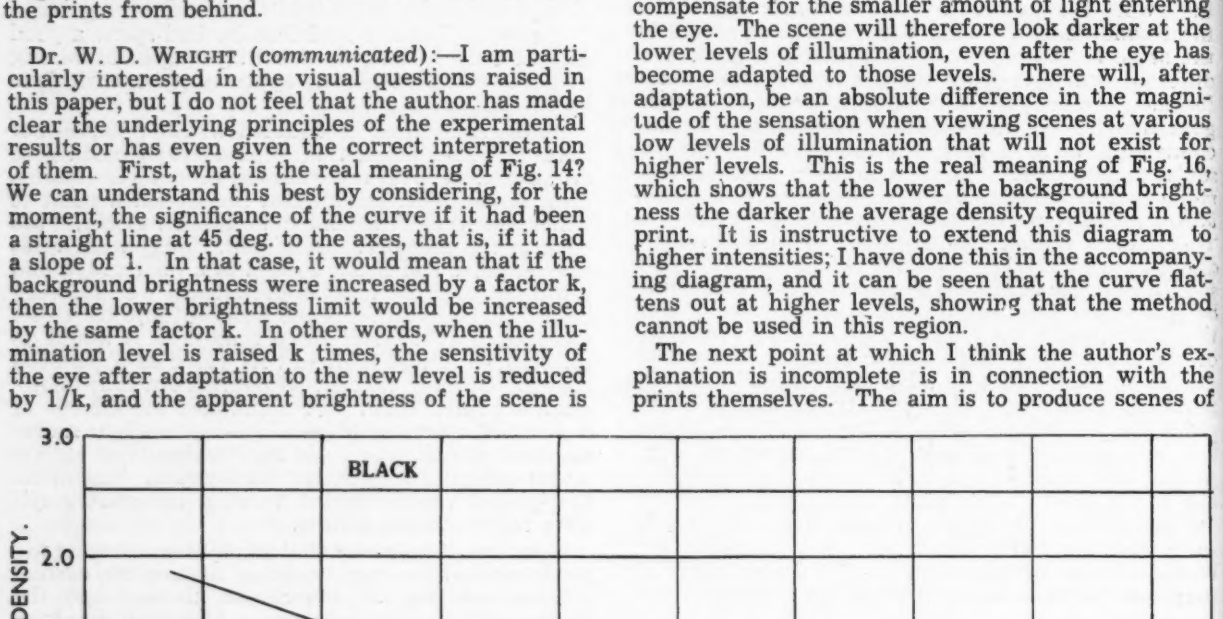
He wished the author had restricted his claim to "true comparison" prints, which should enable two different installations to be viewed simultaneously and on a strictly comparable basis, because this was an important requirement which actual observation in the street could not fulfil on account of the physical limits of time and place.

Mr. A. W. BEUTTELL (President, Illuminating Engineering Society) congratulated the author on his paper, and particularly so because it had been awarded the Illuminating Engineering Society's first Silver Jubilee Commemoration Award. Speaking on the paper, he said he was a little sorry that the author had not made it more clear just what was the purpose of this system. The paper began by making a reference to the engineering value of photographs. Was it suggested that it would be of use for all purposes, including artistic and advertising? The reason he raised this point was the question of the accurate reproduction of brightnesses and its relation to the whole range of brightnesses. What he had in mind from the engineering aspect of street lighting was not so much the sources themselves as their specular reflection due to a wet surface or a burnished dry surface. Could these be represented on a print or would some of them be above the reproducible range and appear equal (the brightness of the white paper)? In connection with viewing these photographs for critical purposes in assessing the value of a street light installation, he also asked the author

whether anything had been done or would it be possible to develop a technique whereby the full brightness range could be obtained by illuminating the prints from behind.

Dr. W. D. WRIGHT (*communicated*):—I am particularly interested in the visual questions raised in this paper, but I do not feel that the author has made clear the underlying principles of the experimental results or has even given the correct interpretation of them. First, what is the real meaning of Fig. 14? We can understand this best by considering, for the moment, the significance of the curve if it had been a straight line at 45 deg. to the axes, that is, if it had a slope of 1. In that case, it would mean that if the background brightness were increased by a factor k, then the lower brightness limit would be increased by the same factor k. In other words, when the illumination level is raised k times, the sensitivity of the eye after adaptation to the new level is reduced by 1/k, and the apparent brightness of the scene is reduced by a factor k, the brightness limit will be reduced by a factor somewhat less than k, so that the gain in sensitivity of the eye is not sufficient to compensate for the smaller amount of light entering the eye. The scene will therefore look darker at the lower levels of illumination, even after the eye has become adapted to those levels. There will, after adaptation, be an absolute difference in the magnitude of the sensation when viewing scenes at various low levels of illumination that will not exist for higher levels. This is the real meaning of Fig. 16, which shows that the lower the background brightness the darker the average density required in the print. It is instructive to extend this diagram to higher intensities; I have done this in the accompanying diagram, and it can be seen that the curve flattens out at higher levels, showing that the method cannot be used in this region.

The next point at which I think the author's explanation is incomplete is in connection with the prints themselves. The aim is to produce scenes of



Theoretical Relationship between Paper Density and Equivalent Background Brightness (Dr. W. D. Wright).

unchanged. This state of affairs would represent the working of an ideal adaptation mechanism and the departure of Fig. 14 from a straight line of a slope of 1 indicates the departure of the actual adaptation mechanism from the ideal. It should be noted that between values of the background brightness of about 5 e.f.c. and 1200 e.f.c., the actual curve approximates very closely to the ideal case. Further, it will be realised that it is impossible to use any method to distinguish the apparent brightness of scenes illuminated between these limits, simply because, after adaptation, there is practically no difference to the eye. (This is partly the explanation why the illumination of a print makes so little difference to its appearance, but contrast with the border round the print also has an effect.) Thus, it appears that the method employed by the author only works because, at the low levels of illumination in which he is interested, the curve in Fig. 14 has a slope different from unity.

The slope in this region is actually less than 1. This means that if the background brightness is varying intensity, but if this is achieved by making prints of different density it might seem that a print A of mean density D, say, under an illumination of 20 f.c., would appear identical with a print B of mean density (D+0.6) under an illumination of 80 f.c. They must, it seems, because the physical stimuli entering the eye in the two cases would be identical. Variation of density is equivalent to variation of illumination, and, as the authors have stated, the latter makes no appreciable difference to the appearance of a photograph. Why, then, does a density variation produce the marked effect that everyone knows is, in fact, obtained? The reason is, of course, that the density of a print is estimated in relation to the brightness of the surrounding border. If there were no border it would be impossible to determine the densities of different prints under various illuminations. This question of the surround of the picture is most important, and it is surprising that no mention is made of it in the paper. Even though the technique described were followed exactly, the results would be upset if the photographs were not mounted on

some agreed and standardised surface. This point can be vividly illustrated if a piece of grey paper be illuminated in an intense beam of light so arranged that nothing else can be seen in the beam. The paper will then appear perfectly white, but as soon as a piece of white paper is introduced the grey surface acquires its correct density.

There are one or two minor points that might, perhaps, be explained more fully. How, for instance, is the equivalent background brightness measured experimentally? There does not seem to be any obvious way in which this brightness can be determined. But a factor 4 between this brightness and the minimum brightness has apparently been found without any difficulty. I think, too, that it should be stated more definitely that the factor 4 is more or less an accidental value. It has no fundamental significance and may range from unity (in the case of the ideal, uniformly illuminated road surface) to, possibly, 100 in a very bad installation. The use of the same value 4 throughout means that the good installations suffer, while the bad surfaces are reproduced more favourably than they should be.

One discrepancy that I cannot quite understand is the deduction that the eye, when viewing the prints, was adapted to about 8 e.f.c., since the average reflection factor was 50 per cent. According to Fig. 13, the minimum reflection density varied from one print to another by as much as eight times and the mean density will presumably vary to the same extent. In this case there would be no justification for assuming the eye was adapted to one mean level: account would have to be taken of the individual variations. Actually, I do not think Fig. 14 can be used to find the lower brightness limit when viewing the prints; the neglected effect of contrast must be included.

The reference to the fact that the true representation prints usually appeared darker than expected, except when viewed on the street itself, suggests that some modification in the technique will be called for, since the object of the photographs is to provide a characteristic representation of the installation to people who are unable to visit the site itself. It may be that the provision of a dark surround would provide the necessary correction.

While these comments are mainly critical, they in no sense detract from the value of the experimental results obtained by the author, nor can they obscure the fact that he has obtained remarkable agreement between his observations and those obtained by other workers under very different conditions and from an entirely different point of view.

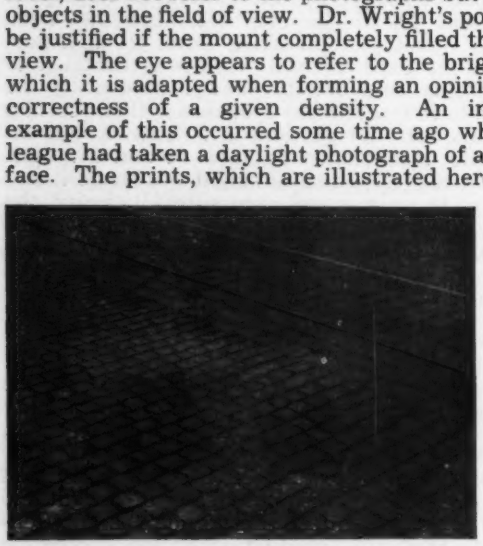
Mr. R. G. HOPKINSON, replying to the discussion, strongly supported what Mr. Wilson had said regarding the improvements made in photographic materials. Without fast panchromatic emulsions or a wide range of printing papers the task would have been very much more difficult. Mr. Smith had pointed out, in a way which left room for no misunderstanding, the necessity for a precise technique for the representation of street lighting installations. Mr. Hopkinson believed it improbable that a photographer who had tried to obtain an accurate record would have obtained a result much worse than Figs. 2 or 3 of the paper, but even these figures, and still more Mr. Smith's illustrations, showed the need for a standard technique.

Most of the speakers on the photographic side had put forward arguments on the application of laws, which had been deduced to confirm the limited range of his experimental results, to general photographic reproduction. He did believe that these laws were applicable, possibly in modified form, to such purposes, but his experimental work was confined to street lighting installations, and consequently he was not able to reply to the speakers without certain reservations. Dr. Wright and Mr. Renwick had explained the significance of Figs. 14 and 16. Dr. Wright had suggested that at brightness levels where the slope of this curve was approximately unity, the method would not work. The significance of this unity slope could be explained by the example, suggested by Mr. Davies, of a dull and a bright day. If the average brightness of a scene on a bright day were ten times that of the same scene on a dull day, the density by which to represent the average brightness would be about the same in each case, as Dr. Wright's curve shows; the only possible difference in the prints would be the representation of any differences in brightness gradation between the two scenes. And, of course, this would be the only difference noticeable in the actual scenes, for it is assumed that the eye has no absolute scale of brightness values. It was very interesting to note, as Mr. Renwick had, that the correlation of the subjective blacks was in accordance with the criterion of the best pictorial photographers.

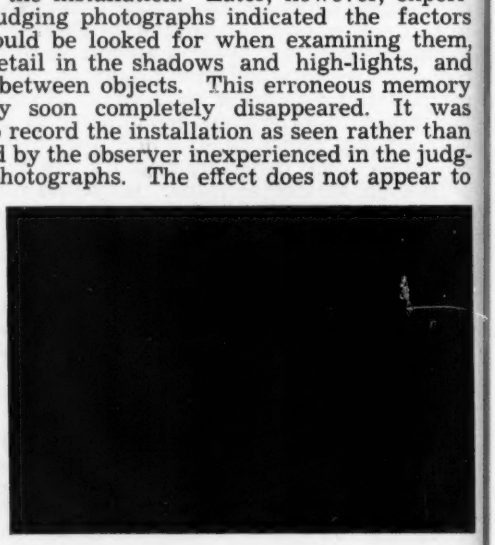
The derivation of densities by Abribat's method, demonstrated by Mr. Davies, was very ingenious. The method was based on the sensation curves which had been derived by Abribat's measurements with an instrument, the optosensitometer, designed for such determinations. Abribat has investigated the problem of photographic representation very thoroughly on the basis of these sensation curves. As Mr. Davies showed, his theory would indicate that unless the sensation curves for conditions of viewing the photograph and of viewing the installation were parallel, the relation between subject brightness and print density would not be a straight line of unity slope. As far as Mr. Hopkinson knew, no work had been done to confirm Abribat's results by the examination of photographs, and as the approximation (Fig. 19) to the straight line, unity slope curve used in the present technique gave good results, he questioned whether a scale of contrasts based on Abribat's theory would differ widely from that curve. It would be necessary, in any comparison, to confirm deductions by this or any other method by the examination of photograph and subject together, as had been done in the investigation.

The effect of the immediate surround, which had been pointed out by Dr. Wright and by Mr. Davies, was not of great significance. Mr. Hopkinson showed three photographs, identical in every respect, mounted respectively on black, white, and grey card. The impression of the installation produced by the

three, he said, could be seen to be the same, because the eye was adapted not only to the brightness of the print but also to the average brightness of all the objects in the field of view, and its adaptation did not seem to be affected by the brightness of the mount, which usually subtended a relatively small angle at the eye. The average value of 50 per cent. reflection factor assumed when calculating the adaptation level, does not refer to the photographs but to all the objects in the field of view. Dr. Wright's point might be justified if the mount completely filled the field of view. The eye appears to refer to the brightness to which it is adapted when forming an opinion of the correctness of a given density. An interesting example of this occurred some time ago when a colleague had taken a daylight photograph of a road surface. The prints, which are illustrated here, had no



Daylight Photograph on Road Surface.



border or mount, and were of nearly uniform density, except for very small variations in density giving the effect of texture in the road surface. In spite of this, there was no difficulty in selecting the print of the correct density.

The range of the eye at any adaptation is limited, as Mr. Renwick pointed out, to about 3,000 : 1, which could be represented on a paper with a density range of 3.5 to 1. The change in sensation of contrast over this range is certainly sufficient to warrant attention being paid to it. The effect of this in the present work is shown in Fig. 19, where it is pointed out that although the paper cannot give a density high enough to represent subjective dead black, the representation does not suffer as much as might be expected, due to the vagueness of detail in the dark regions. It is true, however, that the very bright patches on the road surface obtained by specular reflection on wet or polished roads, all have to be represented by zero density, due to the limited range of the paper. An improvement would be obtained by illuminating from behind transparencies prepared according to the technique given in the paper, but a comparison of transparencies and prints on paper indicate that the improvement is less than might be supposed. Transparencies, although having a greater density range, have a limited use, due to the inconvenience of showing them.

The paragraph on the effect of the memory, which Mr. Davies has quoted in italics, has, unfortunately, conveyed an erroneous impression, and it has, therefore, been altered in the final form of the paper. In the early stages of the investigation some photographs were chosen in the laboratory as being correct. When examined on the installation *under correct viewing conditions* (true perspective, adequate illumination) they were seen to have too low a density. This effect was further examined, and it was found to be due to a faulty recollection of the precise details of the installation. Later, however, experience in judging photographs indicated the factors which should be looked for when examining them, such as detail in the shadows and high-lights, and contrasts between objects. This erroneous memory effect very soon completely disappeared. It was decided to record the installation as seen rather than as recalled by the observer inexperienced in the judgment of photographs. The effect does not appear to be due to a difference in adaptation levels, as Mr. Davies suggests, as it varies with observers and disappears with increased experience. If it were a function of adaptation, all observers should agree. He hoped that this explanation would clear away any difficulties caused by the use of the sentences quoted.

The effect of the glare sources on the adaptation level was not as great as the author had once supposed. Photographs of installations where the sources were obscured gave good representations when made to the standard density scale. The results of Stiles and Crawford, when applied to actual installations, indicated that the glare from the sources did not materially affect the adaptation level. There is still the possibility of detail being reproduced in the photograph that was not visible in the installation due to the immediate proximity of the glare sources, as Mr. Smith pointed out. But Mr. Smith's test was very delicate, and its delicacy is an index of the small effect of glare. This very small gain of detail in the immediate region of the sources does not affect the general impression given by the photograph of the lighting in the installation.

In reply to another of Dr. Wright's points, the measurement of the adaptation level in order to obtain the relation $B_{eq} = 4$ B min. was obtained by calculation from brightness measurements on a number of installations, assuming that an area of given brightness affects the adaptation level to the same extent wherever it occurs in the field of view. The average brightness was determined by a graphical summation, using photographs on which contours of

equal brightness had been plotted. These determinations gave the relation used in the paper to determine Fig. 17. The factor does not vary to anything like the extent that Dr. Wright suggests. It must be a very good or a very bad installation for the factor to approach unity, and it is not likely to approach even ten except on a well-lighted, but wet, road. As has been pointed out in the paper, such a variation does not cause very great inaccuracy in the representation if the standard correlation of Fig. 18 is used, and in the author's view does not warrant the complication of the measurement of adaptation level and of the use of a different correlation for every value of brightness variation.

The limitations, as well as the value, of photographs produced by the technique, should not be under-estimated, but for the purposes for which they are intended they appear to give the most reliable results which have yet been obtained. To reproduce all the effects Mr. Damant considered necessary would require a working model of the street, and a photograph could not be that. The term "true comparison" told only half the story, as it implied the necessity for other photographs as criterion for judgment, and it was hoped that this had been shown to be unnecessary. At present it had been impossible to find any one term which described them adequately, and until such a term had been found it would be preferable to call them "standard representations." Mr. Waldram had given a very apt comparison with the "true to scale" print. They were engineering records, and as such, it was hoped that they fulfilled their purpose. In answer to Mr. Beuttell, it was not suggested that they were applicable to advertising or artistic purposes unless the limitations of photo-mechanical reproduction could be overcome. As Mr. Smith had suggested, the method could probably serve a useful purpose as part of a standard specification.

Finally, Mr. Hopkinson thanked the various contributors to the discussion for the very useful and interesting criticism their remarks afforded.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

Forthcoming Events

Feb. 4th. Dr. J. W. T. Walsh will deliver the **Opening Address** at the **First Meeting** of the **Photometric Section** of the Illuminating Engineering Society *(At the Westminster Technical Institute, Vincent Square, S.W.1)*; **7 p.m.**

Feb. 11th. Mr. H. Buckley on **Classification of Lighting Systems**; and Mr. S. F. Dunkley and Mr. W. R. Stevens on **Thermal Tests of Illuminating Glassware** *(General Meeting of the Illuminating Engineering Society to take place at the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, London, S.W.1)*; **6.30 p.m.**

Feb. 18th. Mr. R. Maxted on **The Application of Subjective Methods to Lighting Problems** *(Meeting of the North Western Area Local Centre of the Illuminating Engineering Society at the Engineer's Club, Albert Square, Manchester).*

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N.B.—The **Annual Dinner** of the Illuminating Engineering Society, originally arranged for Feb. 4th, has been postponed until **March 24th.**

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